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## ***EASTERN KENTUCKY UNIVERSITY***

### **Department of Physics and Astronomy**

#### **Study of Activation Data of Metal Samples from LDEF-1 and Spacelab-2**

April 15, 1994

Final Technical Report

Order # H-13029D

(Principal Investigator: C. E. Laird)

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Prepared for

George C. Marshall Space Flight Center

Marshall Space Flight Center, Alabama 35812

Eastern Kentucky University  
Richmond, Kentucky 40475

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ACTIVATION DATA OF METAL SAMPLES  
FROM LDEF-1 AND SPACELAB-2 Final  
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NASA Contract # H-13029D

by

Dr. C. E. Laird  
Professor of Physics  
Eastern Kentucky University

Gamma-ray spectra obtained from samples flown aboard the Long Duration Exposure Facility have been analyzed to obtain the nuclear species produced in this material by the interaction of this material with protons and neutrons encountered in its 69 month orbital flight as well as to quantify the specific activity (pCi/kg) of these nuclear species. This quantification requires accurate corrections for efficiency, self attenuation, and background. Plans have been developed for archival of the spectra in a form readily accessible to the scientific, engineering and technical community engaged in space research and application. Work has been initiated in the process of estimating the flux of activating particles encountered by material at various locations of the spacecraft.

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## Final Technical Report

NASA Contract H-13029D

### Introduction

Nearly 400 samples from the Long Duration Exposure Facility (LDEF-1) spacecraft retrieved from low-earth orbit in January, 1990, have been counted in low-background counting facilities to study induced radioactivity in spacecraft material. These low-background facilities are found at the Marshall Space Flight Center (MSFC), Lawrence Berkeley Laboratory (LBL), Lawrence Livermore Laboratory (LLL), Savannah River Laboratory (SRL), the Batelle Memorial Institute Pacific Northwest Laboratory (PNWL), Johnson Space Center (JSC), and the Tennessee Valley Authority Northwest Area Radiological Laboratory (TVA). The gamma-ray spectra from the samples are being carefully analyzed to yield the sample specific activity (activity per unit mass). The Department of Physics and Astronomy at Eastern Kentucky University (EKU) has provided analytical support to these laboratory and is involved in the interpretation of the resulting specific activity. In particular, EKU has the specific task of analyzing the spectra taken at MSFC. The National Aeronautics and Space Administration (NASA) has supported previous, continuing EKU effort through contracts NAS8-35180, NAS8-36642, and H-08071D. Specifically, NASA contract H-13029D required the following work:

Work to be performed on data taken in 1992-1993:

1. Gamma ray spectra obtained post-flight from LDEF samples shall be analyzed. Corrections for geometry, self-absorption, detector efficiency and background shall be made. Uncertainties due to counting statistics and experimental errors shall be estimated.
2. Using experimentally-determined activation cross sections, estimates shall be made of activating protons and neutrons, averaged over the mission lifetime at various locations within the LDEF spacecraft.
3. The results of these studies in the form of quarterly progress reports shall be made.

## **Self Absorption Correction**

The computer code EFFATN was originally developed to calculate the efficiency and attenuation correction for the intentional samples of Vanadium, Cobalt, Nickel, Indium and Tantalum<sup>1</sup>. These samples were designed to be 2 inch by 2 inch squares with thicknesses of 1/4 inch or less although some were cut in half for mounting onto the spacecraft. The EFFATN code has proven adequate for such samples activated with 200 MeV neutrons at Indiana University Cyclotron Facility<sup>1</sup>. However, many samples were obtained from the trunnions, clamp plates and other parts of the LDEF spacecraft. The shapes of these samples were generally irregular. In order to obtain an accurate efficiency and attenuation correction for such samples the EFFATN codes has been modified to include rectangular samples, cylindrical samples, and coaxial samples. These modifications have been done under this contract by Robert Kamau as his Master's thesis project. The code EFFATNC is currently available to perform these calculations.

Several of the trunnion sections were layered by cutting at different radial distances from the center. While most of the layers were flattened into nearly rectangular shapes, layer one was not. This geometrical shape does not fit the shapes incorporated into EFFATNC. A major effort has been undertaken to calculate the correction for layer one samples. The modeling of the shape which specifies the position relative to the detector and tracing the gamma ray as it leaves one part of the layer and possibly passes through another has taken a considerable amount of effort. While the code for this correction exists, the validation has not been completed.

## **Specific Activity of LDEF-1 Samples**

The specific activity of many of the LDEF-1 samples have been calculated using the EFFATN code for correcting for efficiency and self attenuation. These results have been supplied to Dr. Alan Harmon at Marshall Space Flight Center. However, a review of these results were begun under this contract because of concern regarding the proper correction for background and the exact placement of samples relative to the HPGe detector. To do this a review of the shapes of the various samples led to a classification scheme cataloging them as to shape and exact distances from the detector. Apparently, early in the counting different combinations of collars and source mounts were used. This places the samples at slightly different distances than was used in the original corrections. Modifications in the calculations for EFFATN corrections to account for these differences have been made.

The background at the low-background counting facility at MSFC shows considerable variation over the period of counting. A review by the Principal Investigator for this contract led to the conclusion that the most statistically significant values are obtained from spectra 172 and 175. Table I contains the net area, statistical

error and counting time for the listed background gamma-ray energies. These background yields and the updated sample positioning information have been used in recalculating the specific activity of many samples.

Table II gives a list of significant gamma rays observed in many of the LDEF-1 samples, the associated radioisotope, gamma-ray branching ratio and half life. These have been used in an automated search and analysis of the samples using more recent EFFATN corrections and the background from spectra 172 and 175.. Tables IIIa-IIIq give the results of these analyses for the intentional samples. The listed information gives the spectrum number (LDEF RUN NO.), the spectrum name, the gamma rays used to correct for slight energy calibration changes as well as the slope and intercept of this linear correction, the EFFATN correction as well as the detector point-source efficiency used in the correction, the corrected specific activity at the time of counting for a given isotope, the specific activity as of January 20, 1990 and the net error in the specific activity. Also, an asterik indicates those gamma rays for which background corrections have been made. Net errors of near or above 100% indicate gamma rays whose emission from the sample are highly unlikely.

## **Related Activity**

Two areas of activity related to this project have been undertaken as part of the effort under this contract. First, the need for improved experimental cross sections to estimate the fluxes of activating particles and to model the activation buildup within LDEF led to a re-evaluation of experimental results previously reported<sup>2</sup>. The focus of this effort was to confirm the results of the experimental measurements and to determine if additional experimental cross sections useful for LDEF analysis could be obtained. As a result of this effort Tony Armstrong at SAIC was supplied with cross section results for Indium which he has incorporated into activation calculations using a Monte Carlo high energy transport code (HETC). The results of this work were reported at the Third LDEF Post-Retrieval Symposium at Williamsburg, Virginia in November, 1993. The proceedings of this symposium has yet to be published.

The second area of activity deals with archiving the results of the activation of LDEF spacecraft material. Some of the initial plans made by the ECU staff have been published<sup>3</sup>. Additional effort was made by establishing data tape cartridges at the University of Kentucky Computer Facility and developing cataloging procedures for data storage. The procedures were tested to insure that spectra could be stored and retrieved from the tape. Computer programs for reformatting the spectra into a common format were developed and a program for listing a spectrum numerically was developed. Another program was developed to allow a user to graphically view a spectrum with a PC computer as well as to do simple peak area analyses. Because of some unresolved details concerning the exact format of the archive, no further work has been undertaken in this effort.

As was the case with previous work on LDEF supported by NASA/MSFC, undergraduate and graduate students have benefited from their participation. Since March, 1992, four undergraduate and two graduate students, including Robert Kamau,



have worked on this project. In the Fall Semester of 1992 Dr. Alan Harmon of MSFC visited ECU to give a seminar and discuss with faculty and students research from LDEF and the Burst and Transient Source experiment on the Compton Observatory. Also, in the Fall Semester of 1993 Dr. Thomas Ward of the Office of Space, Department of Energy, visited ECU and gave a paper on Space Radiation Effects illustrating the need for the LDEF data in space research. Many ECU students other than direct participants have benefited greatly from this research activity.

## REFERENCES

1. C. E. Laird, Study of Activation of Metals Samples from LDEF-1 and Spacelab-2, *91N29297* July, 1991, Final Technical Report, NASA Contract NAS8-36649.
2. C. E. Laird, Study of Proton and Neutron Activation of Metal Samples in Low-Earth Orbit, July, 1985, Final Technical Report, NASA Contract NAS8-35180. *85N32130*
3. C. E. Laird, B. A. Harmon, G. J. Fishman, and T. A. Parnell, Collection, Analysis, and Archival of LDEF Activation Data, p. 111, Part 1, Second Post-Retrieval Symposium, June 1-5, 1992, San Diego, California.

**TABLE I: BACKGROUND GAMMA RAYS FROM BG172\175**

LIVE TIME: 688255 seconds

ENERGY (keV)	NET AREA	ERROR (%)
110.400	1194	27.140
140.660	781	39.560
294.980	1134	19.840
351.630	1527	12.440
389.700	541	40.110
451.340	361	47.370
803.790	423	34.280
816.010	164	46.340
840.580	184	54.350
847.800	299	40.800
882.540	198	49.490
960.910	409	27.870
1040.210	108	56.480
1120.260	300	32.000
1173.070	447	18.570
1197.870	307	29.640
1238.150	156	38.460
1332.100	558	21.330
1765.400	399	19.050
1793.290	117	47.860
1875.210	114	58.770
2613.510	256	28.120

**TABLE II: GAMMA RAY DATA FOR SELECTED RADIO ISOTOPES**

<b>Energy (keV)</b>	<b>Branching Ratio (%)</b>	<b>HalfLife (Days)</b>	<b>+/- (Days)</b>	<b>Isotope</b>
122.06	85.50	271.77	0.050	CO57
136.47	10.69	271.77	0.050	CO57
320.08	9.83	27.70	0.004	CR51
391.69	64.00	115.09	0.004	SN113
477.61	10.39	53.29	0.070	BE7
810.79	99.50	70.92	0.015	CO58
834.83	99.98	312.20	0.070	MN54
846.81	99.90	77.70	0.500	CO56
889.25	99.98	83.83	0.020	SC46
983.50	99.99	15.98	0.400	V48
1037.88	14.10	77.70	0.500	CO56
1120.51	99.99	83.83	0.020	SC46
1173.24	99.90	1924.00	0.400	CO60
1189.00	16.50	115.00	0.200	TA182
1221.00	34.70	115.00	0.200	TA182
1238.32	67.00	77.70	0.500	CO56
1274.53	99.94	949.73	0.730	NA22
1312.05	97.49	15.98	0.020	V48
1332.50	99.98	1924.00	0.400	CO60
1771.51	15.50	77.70	0.500	CO56
1808.65	99.76	262800000	1095000	AL26
2598.57	16.70	77.70	0.500	CO56

Table III(a) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 26

Spectrum Name: IC9V.PCA			Acquisition Time: 1.00 Days						
Sample Mass: 0.053 Kg			Material: Vanadium						
Energy Calibration:			Calibration Spectrum						
Gamma Ray Energy:			295.94	295.35	keV				
Gamma Ray Energy:			1120.27	1120.77	keV				
Slope: 0.998684			Intercept: 0.9976						
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCi/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCi/Kg)	Act. 1/20/90 (PCi/Kg)	Net Error (%)	Isotope
846.53	0.385	33	0.195	0.9024	0.02278	8.560	14.1	135.37	CO56*
888.52	0.376	49	0.289	0.9038	0.02170	13.332	21.2	57.45	SC46
911.33	0.372	0	0.0	0.9045	0.02115	0.0	0.0	61.99	LU172
1037.26	0.349	28	1.172	0.9082	0.01864	62.888	104.0	83.05	CO56*
1120.27	0.336	57	0.336	0.9103	0.01733	19.421	30.9	65.09	SC46*
1172.74	0.328	39	0.230	0.9115	0.01661	13.876	14.2	98.73	CO60*
1237.80	0.319	23	0.203	0.9129	0.01581	12.814	21.1	96.86	CO56*
1332.41	0.308	28	0.165	0.9148	0.01482	11.153	11.4	107.24	CO60*

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

**Table III(b) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 27**

<b>Spectrum Name: IC9CO.PCA</b> <b>Sample Mass: 0.0682 Kg</b> <b>Energy Calibration:</b> <b>Gamma Ray Energy: 122.06 122.05 keV</b> <b>Gamma Ray Energy: 834.83 835.11 keV</b> <b>Slope: 0.999558</b> <b>Intercept: 0.0849</b>									
<b>Acquisition Time: 1.00 Days</b> <b>Material: Cobalt</b> <b>Calibration Spectrum</b>									
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCI/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCI/Kg)	Act. 1/20/90 (PCI/Kg)	Net Error (%)	Isotope
122.06	2.499	3535	18.964	0.6801	0.09560	198.376	229.0	7.12	CO57
136.59	2.082	428	18.364	0.7190	0.09458	194.161	225.0	25.24	CO57*
810.73	0.579	274	1.263	0.8897	0.23490	53.763	93.9	16.44	CO58
834.83	0.571	456	2.092	0.8908	0.22810	91.709	104.0	11.66	MN54*
846.51	0.567	56	0.257	0.8913	0.02250	11.429	19.0	57.12	CO56*
982.72	0.527	58	0.226	0.8965	0.01942	13.701	163.0	57.54	SC46*
1120.24	0.494	46	0.211	0.9008	0.01715	12.307	19.7	72.38	CO60*
1173.18	0.482	124	0.569	0.9023	0.01643	34.646	35.4	24.81	CO56*
1238.01	0.470	37	0.253	0.9040	0.01566	16.180	26.9	94.17	V48
1332.08	0.453	76	0.349	0.9063	0.01469	23.741	24.2	37.67	CO60*

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

Table III(c) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 28

<b>Spectrum Name: IC9IN.PCA</b> <b>Sample Mass: 0.0618 Kg</b> <b>Energy Calibration:</b> <b>Gamma Ray Energy: 569.15 keV</b> <b>Gamma Ray Energy: 1332.51 keV</b> <b>Slope: 1.000787</b> <b>Intercept: -1.22833</b>									
<b>Acquisition Time: 1.26Days</b> <b>Material: Indium</b> <b>Calibration Spectrum</b>									
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCi/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCi/Kg)	Act. 1/20/90 (PCi/Kg)	Net Error (%)	Isotope
124.97	7.558	261	1.225	0.3518	0.04878	25.107	29.1	49.02	C057
139.15	5.676	2	0.075	0.4324	0.05624	1.335	1.6	4059.77	C057*
390.81	0.837	54	0.339	0.8420	0.04763	7.107	10.1	123.15	SN113*
844.94	0.465	23	0.092	0.8941	0.02261	4.085	6.9	181.30	C056*
1121.69	0.386	11	0.044	0.9044	0.01719	2.567	4.2	249.92	SC46*
1173.39	0.396	5	0.020	0.9059	0.01649	1.217	1.2	635.68	C060*
1238.56	0.375	37	0.222	0.9075	0.01571	14.103	23.7	77.34	C056*
1314.70	0.364	51	0.210	0.9093	0.01491	14.078	177.0	39.67	V48
1332.52	0.361	0	0.0	0.9097	0.01474	0.0	0.0	151.12	C060*

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

Table III(d) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 29

Spectrum Name: IC9IN2.PCA			Acquisition Time: 0.59 Days						
Sample Mass: 0.0618 Kg		Material: Indium							
Energy Calibration:		Calibration Spectrum							
Gamma Ray Energy:		569.15 keV							
Gamma Ray Energy:		1332.51 keV							
Slope: 1.001299		Intercept: -1.48004							
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCi/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCi/Kg)	Act. 1/20/90 (PCi/Kg)	Net Error (%)	Isotope
138.93	5.70	61	4.884	0.4312	0.05614	86.988	101.0	123.83	CO57*
390.72	0.837	35	0.468	0.8419	0.04764	9.825	14.0	115.37	SN113*
898.67	0.448	52	1.545	0.8965	0.21270	72.648	77.1	65.65	LU172
1037.58	0.413	28	1.70	0.9018	0.01850	91.865	155.0	66.55	CO56*
1120.51	0.396	12	0.103	0.9044	0.01721	5.969	9.7	184.65	SC46*
1173.56	0.386	6	0.051	0.9059	0.01649	3.117	3.2	301.24	CO60*
1237.12	0.376	27	0.345	0.9075	0.01573	21.932	37.1	72.34	CO56*
1332.51	0.361	2	0.017	0.9097	0.01479	1.162	1.2	825.40	CO60*

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

Table III(e) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 62

Spectrum Name: TAC31.PCA									
Acquisition Time: 0.98 Days									
Sample Mass: 0.136 Kg									
Material: Tantalum									
Energy Calibration:									
Calibration Spectrum									
Gamma Ray Energy: 181.5 181.47 keV									
Gamma Ray Energy: 1221.41 1221.95 keV									
Slope: 0.999448									
Intercept: 0.130112									
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCI/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCI/Kg)	Act. 1/20/90 (PCI/Kg)	Net Error (%)	Isotope
181.50	16.779	253	2.967	0.1759	0.01922	154.405	167.0	50.94	LU172
810.72	1.275	100	0.236	0.7920	0.02091	11.273	23.6	35.50	CO58
846.98	1.226	19	0.045	0.7978	0.02013	2.217	4.4	180.63	CO56*
901.06	1.163	181	1.474	0.8056	0.01906	77.342	83.5	18.65	LU172
911.86	1.152	88	1.395	0.8070	0.01886	73.944	79.8	48.37	LU172*
1093.66	1.002	314	1.160	0.8528	0.01609	72.10	77.8	12.63	LU172
1120.52	0.985	83	0.195	0.8280	0.01576	12.359	23.1	49.35	SC46*
1172.47	0.954	0	0.0	0.8318	0.01516	0.0	0.0	404.31	CO60*
1221.41	0.929	53	0.358	0.8352	0.01465	24.464	38.6	43.80	TA182*
1332.58	0.877	12	0.028	0.8419	0.01364	2.064	2.1	292.84	CO60*
1770.67	0.724	45	0.681	0.8622	0.01110	61.333	120.0	47.05	CO56

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175



Table III(f) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 63

Spectrum Name: TAC32.PCA									
Acquisition Time: 1.92 Days									
Sample Mass: 0.136 Kg									
Material: Tantalum									
Energy Calibration: Calibration Spectrum									
Gamma Ray Energy: 55.8 keV									
Gamma Ray Energy: 1221.41 keV									
Slope: 0.999774									
Intercept: -0.33728									
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCI/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCI/Kg)	Act. 1/20/90 (PCI/Kg)	Net Error (%)	Isotope
139.14	32.332	72	0.805	0.0196	0.00255	315.897	383.0	204.51	CO57*
181.11	16.869	322	1.924	0.0175	0.01913	100.619	109.0	42.96	LU172
809.83	1.276	206	0.247	0.7918	0.20930	11.822	24.8	24.04	CO58
847.01	1.226	50	0.060	0.7978	0.02013	2.973	5.9	126.61	CO56*
900.68	1.164	314	1.303	0.8055	0.01907	68.345	73.8	17.29	LU172
911.84	1.152	184	1.486	0.8070	0.01886	78.784	85.1	32.37	LU172*
1093.71	1.002	581	1.094	0.8258	0.01609	67.982	73.4	10.88	LU172
1120.71	0.985	57	0.068	0.8280	0.01575	4.326	8.1	85.78	SC46*
1172.97	0.954	26	0.031	0.8319	0.01515	2.053	2.1	165.03	CO60*
1188.11	0.946	63	0.456	0.8329	0.01499	30.449	48.1	41.70	TA182
1221.41	0.929	111	0.382	0.8352	0.01465	26.109	41.3	30.32	TA182
1236.74	0.921	19	0.034	0.8362	0.01449	2.339	4.6	198.94	CO56*
1332.40	0.877	31	0.037	0.8419	0.01364	2.717	2.8	158.69	CO60*

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

Table III(g) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 64

Spectrum Name: NIC31.PCA										Acquisition Time: 2.03 Days					
Sample Mass: 0.0768 Kg										Material: Nickel					
Energy Calibration:										Calibration Spectrum					
Gamma Ray Energy:										122.06		122.17		keV	
Gamma Ray Energy:										1173.24		1172.99		keV	
Slope: 1.000339										Intercept:		-0.15041			
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCi/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCi/Kg)	Act. 1/20/90 (PCi/Kg)	Net Error (%)	Isotope						
122.06	2.786	14387	33.786	0.6202	0.08717	387.588	474.0	6.17	CO57						
136.50	2.301	1972	37.039	0.6665	0.08771	422.286	516.0	10.34	CO57						
811.26	0.603	293	0.591	0.8716	0.0230	25.707	55.5	17.42	CO58						
835.44	0.594	641	1.287	0.8728	0.02234	57.636	68.6	12.51	MN54*						
847.77	0.590	307	0.617	0.8734	0.02201	28.030	56.6	19.80	CO56*						
889.44	0.576	56	0.112	0.8754	0.02099	5.357	10.3	55.68	SC46*						
1120.86	0.513	95	0.191	0.8841	0.01682	11.343	21.7	52.34	SC46*						
1173.24	0.502	107	0.215	0.8857	0.01613	13.333	13.7	42.63	CO60*						
1238.36	0.488	154	0.462	0.8877	0.01537	30.030	60.6	30.17	CO56*						
1332.95	0.471	54	0.108	0.8903	0.01442	7.521	7.7	94.59	CO60*						

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

**Table III(h) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 89**

Spectrum Name: NIC32.PCA			Acquisition Time: 3.34 Days						
Sample Mass: 0.0729 Kg			Material: Nickel						
Energy Calibration:			Calibration Spectrum						
Gamma Ray Energy:			122.06 122.29 keV						
Gamma Ray Energy:			1173.24 1173.57 keV						
Slope: 0.999901			Intercept: -0.21692						
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCI/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCI/Kg)	Act. 1/20/90 (PCI/Kg)	Net Error (%)	Isotope
122.06	2.786	19671	29.535	0.6362	0.08942	330.292	464.0	6.09	CO57
136.20	2.301	3019	36.254	0.6801	0.08962	404.513	569.0	10.19	CO57
810.72	0.603	304	0.392	0.8786	0.02320	16.905	62.4	23.14	CO58
834.81	0.594	754	0.968	0.8789	0.02253	42.970	57.8	13.47	MN54*
847.26	0.590	436	0.560	0.8804	0.02220	25.236	83.1	20.22	CO56*
889.41	0.576	64	0.082	0.8823	0.02116	3.884	11.7	39.55	SC46*
1120.94	0.513	0	0.0	0.8911	0.01695	0.0	0.0	142.74	SC46*
1173.24	0.502	215	0.276	0.8927	0.01626	16.994	17.8	33.18	CO60*
1237.81	0.489	147	0.282	0.8946	0.01550	18.177	59.8	37.89	CO56*
1332.48	0.471	55	0.071	0.8972	0.01454	4.858	5.1	129.89	CO60*

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

Table III(i) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 112

Spectrum Name: NIG121.PCA									
Acquisition Time: 3.05 Days									
Sample Mass: 0.0555 Kg					Material: Nickel				
Energy Calibration:					Calibration Spectrum				
Gamma Ray Energy:					122.06	122.16	keV		
Gamma Ray Energy:					1173.24	1173.63	keV		
Slope: 0.99972					Intercept: -0.06486				
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCi/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCi/Kg)	Act. 1/20/90 (PCi/Kg)	Net Error (%)	Isotope
122.06	2.786	11801	25.507	0.6362	0.08942	285.245	404.0	6.29	CO57
136.46	2.302	1798	31.082	0.6808	0.08962	346.844	491.0	13.55	CO57
811.05	0.603	334	0.620	0.8786	0.02320	26.749	102.0	17.23	CO58
834.66	0.594	382	0.706	0.8798	0.02540	31.333	42.4	19.52	MN54*
847.28	0.590	221	0.409	0.8804	0.02220	18.414	62.2	42.69	CO56*
911.92	0.569	0	0.0	0.8833	0.02064	0.0	0.0	174.96	LU172*
1120.27	0.514	9	0.017	0.8911	0.01695	0.981	3.0	635.07	SC46*
1173.24	0.502	107	0.198	0.8927	0.01626	12.175	12.8	63.71	CO60*
1237.75	0.489	73	0.201	0.8946	0.01550	12.994	43.9	63.28	CO56*
1332.46	0.471	0	0.0	0.8972	0.01454	0.0	0.0	639.53	CO60*

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

Table III(j) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 113

Spectrum Name: NIF21.PCA			Acquisition Time: 0.95 Days						
Sample Mass: 0.0555 Kg			Material: Nickel						
Energy Calibration:			Calibration Spectrum						
Gamma Ray Energy:			122.06	122.07	keV				
Gamma Ray Energy:			1173.24	1173.63	keV				
Slope: 0.999635			Intercept: 0.035576						
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCI/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCI/Kg)	Act. 1/20/90 (PCI/Kg)	Net Error (%)	Isotope
122.06	2.786	3442	23.793	0.6362	0.08942	266.078	379.0	6.91	CO57
136.35	2.305	400	22.115	0.6805	0.08962	246.766	351.0	25.94	CO57
810.72	0.603	107	0.636	0.8786	0.02320	27.395	106.0	30.49	CO58
835.14	0.594	137	0.810	0.8798	0.02252	35.959	48.9	25.64	MN54*
846.97	0.590	77	0.456	0.8804	0.02221	20.511	70.5	54.27	CO56*
1173.24	0.502	26	0.154	0.8927	0.01626	9.462	9.9	107.09	CO60*
1238.41	0.488	63	0.556	0.8947	0.01549	35.880	123.0	52.32	CO56*
1332.34	0.471	4	0.024	0.8972	0.01454	1.627	1.7	695.69	CO60*
2599.81	0.338	18	0.637	0.9165	0.00954	66.796	230.0	50.36	CO56*

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

Table III(k) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 114

Spectrum Name: NIF22.PCA		Acquisition Time: 3.33 Days							
Sample Mass: 0.0555 Kg		Material: Nickel							
Energy Calibration:		Calibration Spectrum							
Gamma Ray Energy:		122.06	122.09 keV						
Gamma Ray Energy:		1173.24	1173.66 keV						
Slope: 0.999625		Intercept: 0.016754							
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCi/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCi/Kg)	Act. 1/20/90 (PCi/Kg)	Net Error (%)	Isotope
122.06	2.786	11991	23.714	0.6362	0.08942	265.196	381.0	6.26	CO57
136.37	2.304	1705	26.969	0.6806	0.08962	300.929	432.0	14.57	CO57
810.60	0.603	194	0.330	0.8786	0.02320	14.208	56.7	28.47	CO58
835.17	0.594	573	0.969	0.8798	0.02252	43.031	58.9	14.70	MN54*
846.80	0.590	221	0.374	0.8804	0.02221	16.839	59.6	40.01	CO56*
911.48	0.569	0	0.0	0.8833	0.02065	0.0	0.0	94.19	LU172*
1119.85	0.514	28	0.047	0.8910	0.01697	2.791	9.0	234.39	SC46*
1173.24	0.502	125	0.212	0.8927	0.01626	13.014	13.7	53.05	CO60*
1238.11	0.488	184	0.464	0.8947	0.01549	29.974	106.0	35.33	CO56*
1331.88	0.471	46	0.078	0.8972	0.01454	5.350	5.6	150.30	CO60*

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

Table III(I) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 115

Spectrum Name: NIF23.PCA			Acquisition Time: 3.33 Days						
Sample Mass: 0.0555 Kg			Material: Nickel						
Energy Calibration:			Calibration Spectrum						
Gamma Ray Energy:			122.06	122.46	keV				
Gamma Ray Energy:			1173.24	1173.13	keV				
Slope: 1.000482			Intercept: -0.0458						
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCi/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCi/Kg)	Act. 1/20/90 (PCi/Kg)	Net Error (%)	Isotope
122.06	2.786	12173	24.074	0.6362	0.08942	269.221	391.0	6.27	CO57
136.37	2.304	1789	28.297	0.6806	0.08962	315.759	459.0	14.57	CO57
809.32	0.603	240	0.408	0.8786	0.02322	17.562	73.4	24.07	CO58
834.95	0.594	493	0.834	0.8798	0.02253	37.012	51.2	16.08	MN54*
846.66	0.590	271	0.459	0.8804	0.02222	20.646	76.2	35.82	CO56*
1120.08	0.514	0	0.0	0.8911	0.01696	0.0	0.0	138.11	SC46*
1173.24	0.502	85	0.144	0.8927	0.01626	8.850	9.3	69.96	CO60*
1238.09	0.488	116	0.293	0.8947	0.01549	18.897	69.7	46.29	CO56*
1332.25	0.471	17	0.029	0.8972	0.01454	1.978	2.1	398.40	CO60*

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

Table III(m) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 122

Spectrum Name: H12NIU.PCA			Acquisition Time: 1.16 Days						
Sample Mass: 0.0555 Kg			Material: Nickel						
Energy Calibration:			Calibration Spectrum						
Gamma Ray Energy:			122.06	123.58	keV				
Gamma Ray Energy:			1332.51	1332.32	keV				
Slope: 1.001414			Intercept: -1.69373						
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCi/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCi/Kg)	Act. 1/20/90 (PCi/Kg)	Net Error (%)	Isotope
122.06	2.786	4388	24.977	0.6218	0.08739	285.810	467.0	6.83	CO57
136.26	2.307	602	27.407	0.6650	0.08761	312.846	511.0	22.56	CO57
834.04	0.595	139	0.677	0.8618	0.02209	30.630	47.0	31.76	MN54*
846.13	0.590	33	0.161	0.8623	0.02178	7.382	41.1	121.51	CO56*
1120.96	0.513	11	0.054	0.8731	0.01661	3.224	15.8	235.97	SC46*
1172.06	0.502	53	0.258	0.8747	0.01594	16.194	17.4	69.98	CO60*
1237.70	0.489	88	0.639	0.8766	0.01518	42.099	235.0	39.18	CO56*
1275.63	0.481	68	0.331	0.8776	0.01479	22.396	25.8	38.70	NA22
1332.51	0.471	24	0.117	0.8790	0.01424	8.204	8.8	147.98	CO60*

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175



Table III(n) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 124

Spectrum Name: H12NI2.PCA			Acquisition Time: 1.9 Days						
Sample Mass: 0.0555 Kg			Material: Nickel						
Energy Calibration:			Calibration Spectrum						
Gamma Ray Energy:			122.06	123.87	keV				
Gamma Ray Energy:			1332.51	1332.68	keV				
Slope: 1.001356			Intercept: -1.97694						
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCi/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCi/Kg)	Act. 1/20/90 (PCi/Kg)	Net Error (%)	Isotope
122.06	2.786	7251	25.161	0.6218	0.08739	287.907	475.0	6.69	CO57
136.18	2.307	1131	31.389	0.6648	0.08761	358.285	591.0	13.49	CO57
834.08	0.595	215	0.638	0.8618	0.02209	28.883	44.6	28.42	MN54*
845.71	0.590	89	0.264	0.8623	0.02179	12.131	69.7	62.33	CO56*
1119.0	0.514	40	0.119	0.8731	0.01664	7.135	36.1	110.83	SC46*
1173.23	0.502	60	0.178	0.8747	0.01593	11.186	12.0	105.43	CO60*
1237.41	0.489	49	0.217	0.8766	0.01519	14.287	82.0	84.94	CO56*
1277.39	0.481	80	0.237	0.8776	0.01477	16.081	18.6	59.05	NA22
1332.51	0.471	45	0.134	0.8790	0.01424	9.377	10.1	112.80	CO60*

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

Table III(O) . INTENTIONAL SAMPLE RESULTS: LDEF RUN NO. 136

Spectrum Name: H12NI3.PCA			Acquisition Time: 0.89 Days						
Sample Mass: 0.0555 Kg			Material: Nickel						
Energy Calibration:			Calibration Spectrum						
Gamma Ray Energy:			122.06	123.82	keV				
Gamma Ray Energy:			1173.24	1172.21	keV				
Slope: 1.002657			Intercept: -2.08804						
Energy (keV)	Mass abs. Coefficient	Observed Counts	Activity (PCI/Kg)	Effatn	Corrected Det. Eff.	Corr. Act. (PCI/Kg)	Act. 1/20/90 (PCI/Kg)	Net Error (%)	Isotope
122.06	2.786	2885	21.263	0.6218	0.08739	243.305	403.0	7.25	CO57
135.28	2.335	574	33.835	0.6623	0.08764	386.078	639.0	20.39	CO57
836.15	0.594	122	0.769	0.8619	0.02204	34.897	54.1	31.39	MN54*
847.38	0.590	52	0.328	0.8624	0.02175	15.084	87.8	60.05	CO56*
1119.19	0.514	9	0.057	0.8731	0.01663	3.410	17.4	332.57	SC46*
1173.24	0.502	61	0.385	0.8747	0.01593	24.155	25.9	50.28	CO60*
1235.82	0.489	69	0.649	0.8765	0.01520	42.683	24.8	42.46	CO56
1332.73	0.471	52	0.328	0.8790	0.01424	23.018	24.7	74.00	CO60*
1769.0	0.408	31	1.260	0.8876	0.01144	110.181	641.0	55.17	CO56

NOTE: (\*) INDICATES BACKGROUND HAS BEEN SUBTRACTED USING BG172/175

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Gamma-ray spectra obtained from samples flown aboard the Long Duration Exposure Facility have been analyzed to obtain the nuclear species produced in this material by the interaction of this material with protons and neutrons encountered in its 69 month orbital flight as well as to quantify the specific activity (pCi/kg) of these nuclear species. This quantification requires accurate corrections for efficiency, self attenuation, and background. Plans have been developed for archival of the spectra in a form readily accessible to the scientific, engineering and technical community engaged in space research and application. Work has been initiated in the process of estimating the flux of activating particles encountered by material at various locations of the spacecraft.

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